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SCIENCE

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WHAT IS INDUSTRIAL SCIENCE?[1]

Industrial education is now the most pressing of all educational problems. It is, moreover, a wholly new problem; since the schools have never seriously tried, until very recently, to grapple with it. Up to the beginning of this twentieth century, the working hypothesis of the schools has been that the best possible education for every boy and every girl was that portion of a college education which each was able to secure. The banner of education bore the inscription: "Keep the path open for every child from the kindergarten to the university." The intention of this motto was good, in that it was supposed to express the idea of equal opportunity for all; but it was interpreted by schoolmen to mean that the college course was infallibly the best possible course for everybody; and that, therefore, the elementary schools and the high schools were doing their work most efficiently if those who survived their ordeal could successfully get by the guards at the gates of the colleges.

The rapid development of educational insight in the past decade has shown the fallacy of assuming that the same opportunity for all was synonymous with equal opportunity for all. The desire to discover what equal opportunity for all might mean has led to much careful study of the individual differences and of the individual needs of pupils, and also to some careful analyses of the foundations of school philosophy. These studies have shown school-

[1] Presented at the meeting of the Central Association of Science and Mathematics Teachers at Des Moines, November 29, 1913.

men that, turn and twist as they may, they are always face to face with three mighty facts. These are: (1) That the present age is an age of machines, with a new set of ideals of its own; (2) That the schools are still too much under the influence of the ideals of a grammatical, machineless age which is now rapidly passing away; and (3) That not only industry, but also the public at large, is demanding a new type of schools whose graduates shall feel at home in and be able to cope successfully with this modern world of machines.

Now facts are facts, whether we like them or not; and it is a hopeful sign of growth that schoolmen are no longer trying to obscure these three great facts by devout longings for the will-o'-the-wisp of culture for its own sake. We schoolmen have reached the point where we are seriously trying to harmonize these relatively new facts with the rest of our knowledge. Such, at least, is my attitude in trying to define what, in the presence of these facts, science might do to help the schools to usher in a new era of real industrial education.

That we are all trying to find out what industrial science may mean is proof that we are all pretty well agreed that the work now done under the name of science in most schools can not fairly be called industrial science. Whether that work may justly be called science or not is another question, and one about which there have been and still are perfectly honest differences of opinion. But this is not the topic under discussion. The problem before us is: What is industrial science? and I assume that all are ready to agree that few, if any, have yet defined it in action; *i. e.*, that few, if any, of the present school courses in science can be classed under that head. For the sake of definiteness, this problem will first be discussed for the special case of physics. The conclusions reached are equally valid for the other sciences.

Current courses in physics do not meet the demand for industrial physics because the leading ideas on which most of the elementary work in physics is based are fundamentally different from those required by industrial physics. Current courses in elementary physics have been planned by students of advanced physics under the spell of a very one-sided appreciation of what the essential elements of physics are. For when a student undertakes to grapple with such works as Newton's "Principia," or Maxwell's "Electricity and Magnetism," he finds it no easy task merely to follow the argument and to reproduce the results. Hence he naturally acquires a great admiration for the intellectual genius of the men who created such works. He knows, moreover, that his academic success depends on his ability to reproduce these works as intellectual feats only. When he himself becomes a teacher of elementary physics, he very naturally falls into the habit of presenting physics as a series of intellectual feats—of facts and demonstrations and theories and nothing more. Hence current courses have been framed and many text-books have been written with the sole purpose of teaching the laws and principles of elementary physics as coldly intellectual propositions.

As teachers of elementary physics we have thus been filled with a zeal to impart to others the principles that have cost us so much labor. We have tried to get beginners—mere infants in physics—to repeat Newton's laws of motion with some show of intelligence as to their meaning; we have had them figure coefficients of restitution, although none of us ever met one in real life. We have even let them speculate about atomic magnets and ether and

the kinetic theory of matter, long before they have enough facts at their disposal to make these theories comprehensible. This was natural enough—did not the great artists who created the science of physics do these things? But, somehow, it did not work. It was all too unusual and too abstract and too remote from the interests of real boys and girls. It was too coldly intellectual to satisfy the demands of a world of action and emotion. It was too much like learning and trying to apply the fixed rules of grammar to be really exciting. We therefore had to give it up and try again.

In the second attempt we shifted our enthusiasm from the works of men like Galileo, Faraday and Helmholtz, to the achievements of men like Watt, Stevenson and Wilbur Wright. In other words, we seemed to be giving up trying to make scientific artists out of all of our pupils, and shifted the emphasis over to an ambition for engineers. Not that we forsook entirely the traditions of the past—far from it. We merely tried to use the inventions and achievements of engineers as a bait with which to catch the unwary on the laws and principles aforesaid. We tried to use a boy's natural enthusiasm for steam engines as a means of painlessly inoculating him with the errors of thermometers, the laws of boiling, the laws of fusion, the laws of saturated vapors, and the mechanical equivalent of heat.

This second attempt was a great advance over the first, in that it showed some recognition of the rights of the victims—it took some account of the desires and emotions of the pupils. But even this plan has not succeeded. It is at best a sorry practise to try to make any subject-matter interesting after it has been selected on grounds other than the interests of those who are to learn it. This practise has not and will not satisfy the demands of industry or teach boys and girls to cope successfully with a world of machines. If it had and would, we would not now be still seeking the meaning of industrial physics.

From the first of these experiences we have learned that an age of machines is not satisfied with a physics teaching that makes a few men competent to reproduce statements of the laws of physics as coldly intellectual propositions at college entrance examinations. From the second we are discovering that the public does not consider that it is getting its money's worth out of a physics teaching that turns out a moderate number of boys and girls with a moderate amount of information about engines, trolleys, telephones and wireless, and some painful memories of a few laws and principles as an added ornament.

Both of these attempts at teaching elementary physics in an age of machines have failed for the same reason; namely, because it is not possible to gain an understanding of this age merely by counting cogs and levers, or by measuring moments and coefficients, or by speculating about atoms and ether. We have in it all overlooked the fact that the works of the great artist creators of the science of physics and those of the great engineers of physics are not intellectual or material products plain and simple, but are the expressions of a mighty spirit worked out through keen intellects into tangible form. The great physicists are great not because they merely have more brilliant intellects than most people. There are relatively many brilliant intellects and relatively few great scientists. The great engineers too have not been great merely because they possessed great intellects. Both the great physicists and the great engineers have been great because they were inspired with the spirit of science. Keen intellects are, of course, necessary too, but they are not the

determining factor. The power in such men has been, is, and always will be found in the spirit with which they work—in their disinterested devotion to their tasks and their sublime faith in the harmony of nature and in the possibility of achieving what they have undertaken.

This is no new or startling theory. It is a very venerable fact. Yet somehow it seems to have escaped attention entirely in the organization of elementary physics courses. Since the spirit of science is the dominant factor in making a great scientist, we physics teachers have not been quite bright in thus omitting it from our courses. We have been trying to play Hamlet, but have inadvertently omitted Hamlet altogether. It is encouraging to note, however, that the importance of this omission has just begun to attract attention. Some progressive teachers include the biographies of physicists in their courses, and some progressive authors include the portraits of great physicists in their texts. If the materials of physics can not be presented in such a way as to arouse a real live scientific spirit inside a boy, it may be well to show him pictures and to tell him stories of men who had it.

Yet, after all, we physics teachers are not so very much to blame for omitting the scientific spirit from our courses. If we had been inspired with it when we were children, all would have been different. When we were young, nobody knew what it was. Great scientists just felt it and lived it, but nobody seemed to think of trying to describe it, or to define it, or to tell how it felt all welling up inside and overflowing in laws and principles. There have been many attempts from Aristotle down to the present time to define the scientific method of thinking. But it is only very recently that the effort has been seriously made to portray in words just how the scientific spirit feels when it is once safely lodged inside a man.

Now that we are beginning to know something about how it feels to have the scientific spirit inside one, the stone which the builders of elementary physics courses rejected is to become the headstone of the corner of the new industrial physics. For, though they may not know it yet, the thing that the industries need most just now is this self-same scientific spirit. The public is demanding it, employers are seeking it, trades unions are hunting it everywhere, even in socialism, and the world at large in this machine age is crying out piteously for it. If we are ever to have an industrial teaching of science, it will be of a sort that succeeds in developing the scientific spirit inside people. It will be a kind of teaching that does not emphasize the loading of the intellect with facts, principles and theories; but rather one that sees to it that at all costs the hearts of the pupils are filled with the scientific spirit. Hence if we would go forward with the development of industrial physics, we must first recognize what is the essential thing in the scientific spirit.

The essence of the scientific spirit is not, as has been generally supposed, a method of thinking. It is not the intellectual process that has been divided into the steps called observation, induction, hypothesis, verification. This process, if it signifies anything real, is at best but one of the modes in which the presence of the scientific spirit inside is made manifest. Many of us have consciously tried, and as consciously failed, to impose this order of thought on our pupils with the idea that we were thereby serving science. We have failed because the essence of the spirit we want is not of this sort.

The essence of the scientific spirit is an emotional state, an attitude toward life and

nature, a great instinctive and intuitive faith. It is because scientists believe in their hearts that the world is a harmonious and well-coordinated organism, and that it is possible for them to find harmony and coordination, if only they work hard enough and honestly enough and patiently enough, that they achieve their truly great results. It is this faith inside them that inspires them to toil on year after year on one problem. How else could Darwin have toiled on all those years to find coordination in one direction? Was it because he wanted to make himself unpopular with the theologians and to set their tongues to wagging against him all over Christendom? Or was it because the problem interested him, and because he knew in his heart that there must be such a thing as law and order among living organisms, and that such order could be found if only he worked patiently enough and honestly enough?

The same is true of inventors and engineers. Their greatness does not depend primarily upon the fact that they have keen intellects and use scientific methods of thinking. When Wm. McAdoo conceived the idea of the Hudson River tunnels, it was not the idea alone that made him achieve them. Many others had thought of tunnels under rivers before. It was rather his belief that the thing was worth while, backed by an indomitable faith in things and in men. He knew in his soul that the people needed this and that it could be done, and he knew it with such energy that he succeeded in accomplishing it. Brains were useful and even necessary too; but the real source of his success was the will to do, and this in turn comes from a profound and indomitable faith that there is law and order in the world and that therefore it can be done.

Look where you will at physics in real life, and you will always find that the heart and soul of it is an unquestioned faith in things and in the harmony and relatedness of things, united with an unquestioned faith that it is possible for any man to find harmony and relatedness among things if he devotes himself whole-heartedly to the task.

Look where you will at physics-teaching in the schools, and what do you find? Hundreds of teachers—all of us—bustling around with definitions of the unit in physics bound over our eyes. Open any one of these definitions, and what do we find? That the teachers must see to it that each pupil does not less than 30 experiments described in the following list; that teachers should use algebra and geometry when they find it convenient; that teachers should not confuse the pupils with too elaborate apparatus nor allow them to obscure their results under unintelligible units. Hereunto is appended a mighty syllabus, which has cost some committee many hours of hard labor, and which contains the united wisdom of the committee as to what must be included in the course. Such a syllabus of topics we all carry with us always lest we forget some weighty or massive point, and so leave a vacant space in the logical system with which we are trying to adorn our pupils.

So long as we teachers insist on keeping such definitions and such syllabi before our eyes, so long will a real industrial physics be impossible. The syllabus of industrial physics contains only one topic, and that is a topic that no teacher or committee of teachers has ever yet thought of putting in any syllabus yet made. This may seem strange to us at present, with our eyes all blindfolded in our present stately game of blind-man's bluff; but twenty years from now, when our eyes have been opened and industrial physics is in full swing everywhere, the tables will be

turned. We will then wonder how we ever could have been such silly boys as to have been blinded by syllabi that utterly fail to mention the one and only thing that gives science its final and distinctive claim to a leading place in any system of truly democratic education.

The syllabus of industrial physics will be brief and full of meaning. It will read somewhat like this: Topics I–XC, Paragraphs A–Z. The Scientific Spirit. This includes: (1) a militant faith in things, in the harmony of things, and in what men can do with things; (2) an eagerness to seek facts and to treat facts as facts; (3) an imagination that is able to see old facts in new perspectives.

This syllabus contains no topics like those in which the current syllabi abound, because there are plenty of books in which all these topics are fully treated. If a man has the scientific spirit, he will look them up in books whenever he needs any of them so that they come to have meaning for him in the joyous work of living. This is no more than he now has to do if he wants really to use those now covered in physics courses in any important undertaking.

This syllabus contains no required list of experiments; because, to a man with the scientific spirit, all life is one magnificent series of experiments.

This syllabus, finally, contains no petty directions to the teacher; because the result demanded is emotional in nature and depends on the tact, the intuition and the scientific spirit of the teacher. Fortunately no one has yet attempted to formulate set rules for the development and administration of the scientific spirit, so there is hope for success here by a real live teacher.

Like all truly great things, this syllabus is beautiful because of its simplicity. It is, moreover, the same for all the sciences. Committees will not have to waste much valuable talent haggling over its details, but can spend the time thus liberated in learning to apply it. Hence, when it has once been adopted, progress in industrial science will be rapid.

There are a number of reasons why it is certain that this simple syllabus is the one that industrial science is going to adopt. In the first place, this is the syllabus that the colleges now want to have adopted. It is the syllabus that the universities use in their advanced work, and the one that the colleges would like to adopt for their own use if only the secondary schools would be good enough to forget the old syllabi that the colleges made. Although the colleges really want to have this new syllabus adopted, none have yet had the bravery to say so openly; because the new syllabus demands a result which can not be examined in two hours by the college entrance examination board. Even the colleges that lie outside the influence of this board, and that admit wholly on certificate, still like to hold on to the possibility of giving entrance examinations if they ever should want to do so. Standards of something-or-other seem somehow to be maintained by this process.

In the second place, the elementary schools are demanding the adoption of this syllabus of industrial physics. In fact, the elementary schools are seriously trying, with their nature study and their general science, to put it into effect themselves. They know that most children come to the first grade with marked symptoms of scientific spirit cropping out all over them, and they know that these same children leave the eighth grade with their scientific spirit a sad caricature of its original self. But the elementary school can not both make its own teachers and teach the children. The teachers must come from above; and hence progress will be slow until the

high schools, the normal schools and the colleges take hold and help too. That it is decidedly to their own selfish interest to do this is perfectly obvious. If the scientific spirit of the children could be preserved instead of deadened in the schools, the work of the higher institutions would change utterly—would become veritably inspired.

But finally, and most important, the syllabus for industrial science is the one just outlined because it is the one that commerce and industry and the public and the world at large are demanding of the science teachers. This is evident because the history of the development of our civilization shows that, since the destruction of Rome, progress has consisted in a continual series of triumphs by men who believed in things over men who believed in words. Magellan believed in things; and when his fleet had sailed off the west end of the world and sailed safely back on to the east end of it without being seriously inconvenienced by the feat, the words of those who liked to prattle about flat worlds became rather insipid. Watt, and Stevenson and Fulton believed in things so vigorously that they actually succeeded in reducing this earth to about one-eighth of its former size, and in expanding the strength of men to the *n*th power. No amount of talking could ever have accomplished that. The telegraph, the telephone and wireless have compressed the world to still smaller dimensions. The Hanseatic League, the craft guilds, the so-called Renaissance, the development of a merchant marine, the expansion of industry and commerce, are all the work of men who had faith in things. The effects of this work are not material only; for the tangible results of it have been silently working on men's ideals all the time and as silently reconstructing them. It has done more to make men comprehend the idea of universal brotherhood than all the words that were ever uttered about it.

All this is work of the scientific spirit as here defined. It is forcing on us new conceptions of goodness and justice, new ideals of success and failure. It is even developing in us a new faith; for the scientific faith in things and in the possibility of finding among things a harmony which includes them all is now expanding into a faith in men and in the possibility of finding among men a justice which includes them all. This fact appears explicitly in the work of Taylor and others on scientific management, and implicitly in the change that is rapidly coming over business methods everywhere.

The prophets of our time are telling us that a few years ago the general idea underlying business and industrial transactions was "get all you can out of everybody and give as little as you can in return." Business is business was the motto. While this idea still pervades much business, the most successful firms at present are those which have felt the inspiration of this expanded spirit of science and which therefore realize that this idea is, in the light of the facts, a false one. To be permanently successful in business or industry, one must deal with the same people for long periods of time; and this is possible only when all parties to the transaction are satisfied. All parties will be satisfied only when there is mutual confidence in one another and a recognition that all have been treated fairly and justly. This means that business and industry are coming more and more to be guided by men who have a faith in men as well as in things, and who believe that there must be a social and economic order which will give a justice that is best for all and which can be found if men seek it long enough and honestly enough. Business men are coming to this faith, not be-

cause it is a pious moral thing to do, but because it produces tangible results. If workmen feel that they have been treated justly, they are happy and take interest in their work; and happy and interested workmen are more efficient than unhappy and rebellious ones. It pays to treat men justly and to seek a justice that is best for all. The scientific spirit always pays when intelligently applied.

Now it is because the people sense the fact that this expanded and more mature scientific spirit is coming to the front in business and in industry, and because they see that it pays, that the public is demanding the development of scientific spirit in the schools. The situation is full of meaning for teachers of science. In the first place, it is evident that the public has come to believe in the scientific spirit. The public has tasted of this spirit and is bound to have more. If the present schools will not supply it, the public will either make it themselves in business, or found other schools that can make it. Are not the business men of Illinois even now trying to have a second set of schools established in the hope of securing just this? Present schools are beginning to have competition in this development of scientific spirit. Syllabi of facts are no longer the sacred symbols of the faith—it is spreading of itself wherever men are honestly trying to cooperate in work that is significant to them. If we science teachers do not wake up to this situation, our jobs will soon be gone, and the schools may be reduced to the function of teaching the three R's.

Besides, we science teachers are really rather dull when we allow our individualities to be submerged by syllabi and definitions of units. Why do we insist on hiding our light under a bushel of facts and principles of elementary science, all of which can be bought for a dollar and a quarter from any one of a dozen enterprising publishers? And why do we all suppress our personal enthusiasms and all try to make ourselves up to look each as much like the other as possible, and all as much as possible like forty experiments from the following list? That we do so is the more surprising when we realize that we are thereby not merely faithless to our trust as guardians of the scientific spirit, but that we are in addition actually making for ourselves a whole lot of tedious and unnecessary work. It is a great deal easier to develop scientific spirit in lively youngsters than it is to suppress their liveliness with an inherently barren and uninteresting syllabus. It is vastly more fun for the teacher too, if he will just be himself and let his enthusiasm spread through the class. He will not have to be a slave to examination papers and notebooks if he can get the class to working on problems that are really significant and worth while in their eyes. When he sees a class so absorbed in the things they are doing that they forget when it is time to go to the foot-ball game, he can be perfectly sure that they have acquired the scientific spirit and hence need no further examinations. They will then have mastered the syllabus of industrial science.

That we are rapidly drifting toward such work is shown by the success of those experiments in which boys spend half their time in school and the other half in some shop. The shop lends reality to the school work and makes it seem worth while. But the schools might make their work seem worth while without the shop, if only they would adopt the syllabus of industrial science in place of the syllabi that have been standardized by the authority of official utterance of the committee of ten. Those syllabi belong to the age that trusted in words; the syllabus of industrial science

belongs to the age of machines, which is founded on a faith in men and in things.

If I were to stop here, I would have defined industrial physics in its fullest sense. I would not, however, have given any specific directions as to how to go to work to frame a real course in industrial physics. What subject-matter shall be used? What topics? These are very practical and very pressing questions in the every-day routine of schools. To such questions as these there is but one answer; namely, use any subject matter in which you can get your pupils so absorbed that they forget everything else but the thing they are doing. Use the subject-matter of the old syllabus, if you want to, and if you think that you have the genius so to clothe it with significance that all the students will become absorbed in it. It is not absolutely impossible to do this. Experience seems to indicate, however, that teachers will have more success if they change the type of problem from the kind in which only physicists are naturally interested to a kind that has more local color and that the rest of the world find essential. For example, instead of trying to interest the pupils in the errors of thermometer scales, the specific heat of aluminum, or the coefficients of expansion of iron and brass, why not set the class on the problem of finding the best grade of coal in town? Or perhaps they would find the relative efficiencies of various types of cooking utensils and gas stoves a fruitful topic? If such topics as these seem to lack the appeal to the creative instincts, the design and construction of an electric lighting system for a house or a miniature town might prove more stimulating. If this still seems to lack the vitality of the real thing, organize the class into a scientific information bureau and invite the citizens to send in their real problems to the class for solution. A plan of this kind, in operation in Springfield, Mass., was described in the November number of *School Science and Mathematics*. It suggests rich possibilities.

The best example of industrial science that I know of is the work of the corn clubs and the canning clubs of the south. This work was started and is being guided by the General Education Board, and is wholly independent of all school systems. It has, therefore, not been standardized to death. Corn clubs are for the boys, and their purpose is to see which boy can raise the greatest number of bushels of corn per acre. The boy who, by his careful attention to this work, actually produced 210 bushels from his acre, as well as all the other boys involved, incidentally have been raising other things than corn. They are beginning to have faith in things and in what they can do with things. They are beginning to appreciate the value of facts as facts. Their imaginations are at work, figuring, perhaps, how they may slip the corn belt down south and leave Illinois, with its measly 34 bushels per acre up in the cold. They are contributing to the world's work. They are having real industrial science.

In like manner, the canning clubs are for the girls. They meet at the houses of the members and can tomatoes which they have themselves raised. They work with enthusiasm, and have so far perfected their product that, in open market, they get two cents a can more for it than is paid for factory brands. Unlike factory hands, they are happy in their work. They are learning that the scientific spirit pays. Like the boys, the girls have been raising other things as well as tomatoes. They too are beginning to master the syllabus of industrial science, and to have faith in things and in facts, and to see the world in a new perspective. If this sort of work continues and develops farther, who knows but that

the north, with its highly standardized school system, may have to import its scientific spirit from the corn and canning clubs of the south? If we science teachers wish to avert such a humiliating catastrophe, there is but one thing to do; go to work and develop an equally efficient industrial science in the schools.

This is the only thing that will statisfy the present demand of the public and convert the schools of a machineless age into educational institutions that will turn out pupils competent to understand and to cope with this age of machines. For machines are one of the products of science; and if they have caused misery and slavery among workmen and have reduced human beings to machines, it is because they have been owned and manipulated by men who did not possess the scientific spirit. Machines are bound to master and to control men who try to manage them with words or with the ideals of the past machineless age. Only men with the true scientific spirit are able to understand the real meaning of machines and to use their power for the uplift of humanity. Only men with the sacred faith can ever hope to master and to control them permanently.

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THE FUNCTIONS OF AN ENVIRONMENT[1]

In its nature the present paper falls within the field of abstract physical science, and it can, I fear, interest biologists only through its conclusions. But there is reason to believe that by means of these conclusions a trustworthy foundation for the systematic study of the environment may be established.

The result of my recent inquiry into the relation between the organism and the environment[2] has been, as I believe, proof that a hitherto unrecognized order exists among the properties of the elements. This new order is, so to speak, hidden, when one considers the properties of matter abstractly and statically. It becomes evident only when time is taken into consideration. It has a dynamical significance, and relates to evolution.[3] It is associated with the periodic system of the elements in somewhat the same way that the functional order is related to the structural order in biology. Hence it is not independent of the other order, but may be said to lie masked within it.

This is no novel experience, that the consideration of phenomena in time should lead to new points of view. In truth, it might almost have been said *a priori* that a new order must be revealed by a study of the properties of matter in relation to evolution.

This order may be described abstractly as follows:—The properties of matter are not evenly distributed among the elements, nor in such a manner as can be explained by the laws of chance, nor are they altogether distributed in the manner which the periodic system describes. If the extremes be considered, all the physical and chemical properties are distributed with the very greatest unevenness, so that the extremes are concentrated upon a few elements, notably hydrogen, oxygen and carbon. As a result of this fact there arise certain characteristics of the cosmic process which could not otherwise occur.

The characteristics which make up this unique ensemble include the greater number of characteristics and especially the most important and the most conspicuous physical and chemical properties. This order has for cosmic and organic evolution extremely important results—maximal stability of physico-chemical conditions and maximal complexity in the physico-chemical make-up of the surface of a planet; further, the possibility of maximal complexity, durability and activity of physico-chemical systems in such an environment.

All the considerations upon which these results are based are purely physico-chemical,

1 Read before the American Society of Naturalists, December 31, 1913.

2 "The Fitness of the Environment: An Inquiry into the Biological Significance of the Properties of Matter," New York, The Macmillan Company, 1913.

3 I do not, of course, refer to radioactivity, and the possible evolution of the elements.